Relationships between sedimentary, diagenetic and tectonic structures to quantify karst groundwater reserves at the regional scale. Example of the Toulon area (SE, France)

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INTRODUCTION

In the Mediterranean area, karst aquifers are important **groundwater reserves** nested in carbonate series that experienced complex geodynamic and climatic histories. It is commonly admitted that the sea level decreases during the messinian and quaternary regressions strongly condition the deep drainage of these aquifers through the development of **large karst conduits** that are currently drowned. It is important to characterize the influence of geological structures (lithologies and faults) on karst groundwater flow at regionale scale. Here we describe a multidisciplinary approach that couples **balanced cross-sections, sedimentological approach, springs monitoring** (electric conductivity, temperature, water head), hydrochemical analysis, and geophysical properties of rocks.

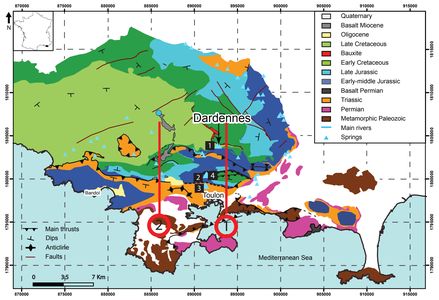


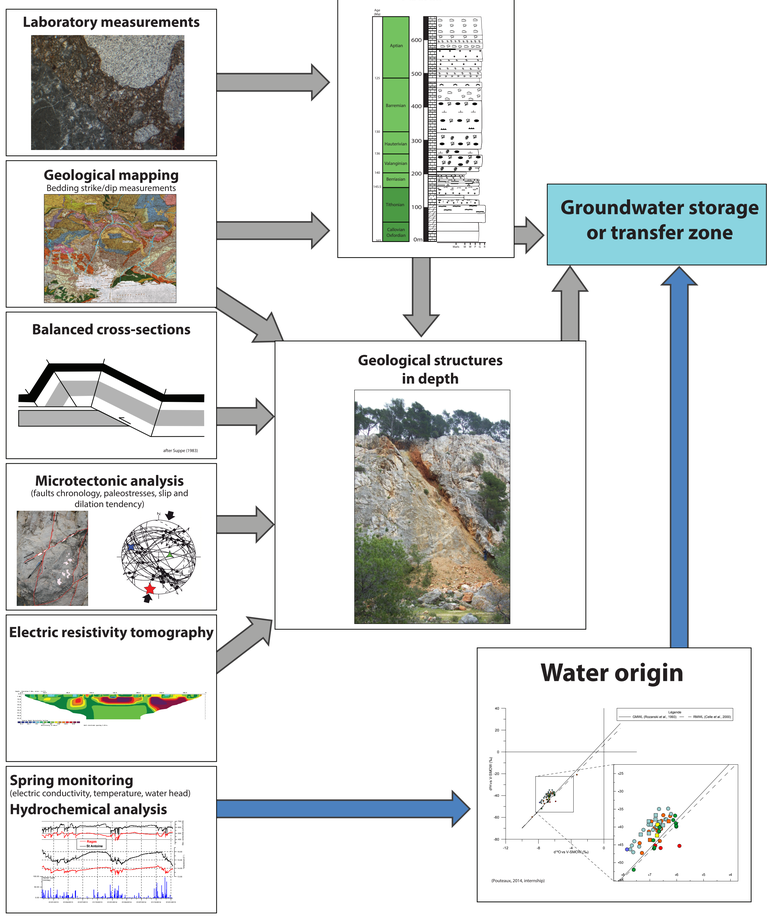
Fig 1 : Structural map of the Toulon area (SE, France). Location of two cross-sections, studied springs (1) Dardennes, Ragas, (2) St Antoine, (3) Rodheillac and (4) studied quarry.

Situated at the boundary between the crystalline and the carbonate Provence, the **Toulon** area is characterized by a geological complexity typically influenced by several evolutions.
Dardennes karst springs (represented here by the **Ragas** spring) and **St Antoine** spring are studied because of their high permanent flow that allows the water supply of the city of Toulon. These springs and the Rodheillac wells are the main output of the hydrogeological system.

Aims of the study

Characterisation of :
- Lithologies/ facies in depth
- Geological accidents/faults
- Storage or transfer zone

WORKFLOW

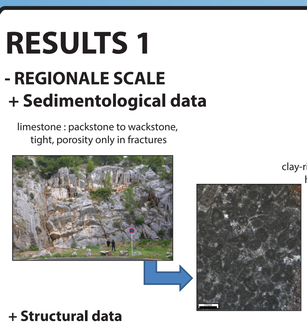


RESULTS 1

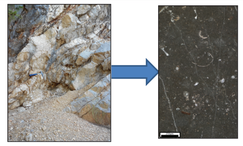
- REGIONALE SCALE

+ Sedimentological data

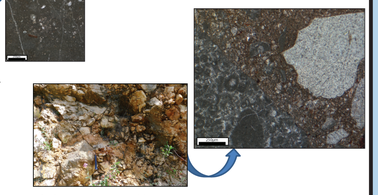
limestone : packstone to wackstone, tight, porosity only in fractures



clay-rich limestone : nodule, charophytes, high porosity, low permeability



Breccia in fault zone : limestone blocs, two cement phases of sandstone, high oxydation, fluids circulations

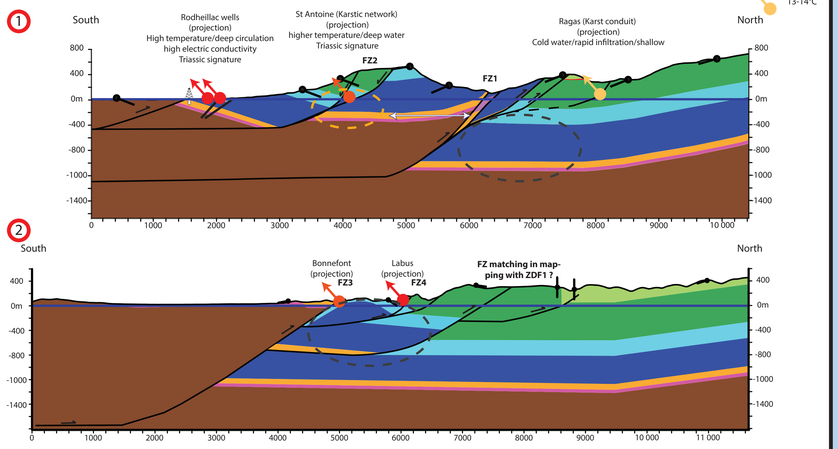


+ Structural data

In these two locations, we observe deep structures that would affect groundwater flow. Fault zones (FZ) represent barrier or transfer zone, here **FZ1 and FZ3** are barriers to groundwater flow with a lift up of the basement = **storage zone**
FZ2 is a very transmissive zone with karst features, connected to St Antoine spring (shown by artificial tracer test).

The transit between these two zones is through Trias (permeable lithology)

Springs temperatures
18-20°C
15-16°C
13-14°C



+ Hydrogeological data

	Springs	Date	O_2	Sp Conduct.	Temperature	pH	Ca^{2+}	Mg^{2+}	Na^+	K^+	SiO_2	TAC	F	Cl^-	Br^-	NO_3^-	NO_2^-	PO_4^{3-}	SO_4^{2-}
			mg/L	°C in situ µS/cm	°C in situ		mg/L	mg/L	mg/L	mg/L	mg/L	mg HCO_3^-/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Downstream	Puits Rodeilhac	16/03/2015 10:15	8,73	840	16,5	7,02	126,65	17,48	20,79	2,75	6,43	309	<ldd	31,68	<ldd	33,10	<ldd	<ldd	108,39
	Saint Antoine	16/03/2015 11:00	9,8	562	15,2	7,12	88,74	12,98	13,07	1,02	4,09	287	<ldd	21,62	<ldd	6,22	<ldd	<ldd	36,01
	Ragas	12/01/2015 13:50	10,9	518	13,8	7,7	106,3	13,9	4,2	0,5	4,16	304	<LD	5,1	<LD	2,2	<LD	<LD	15,4

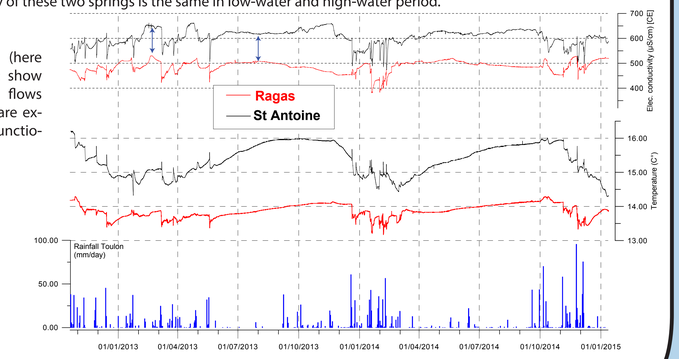
Increase Sp. Cond. & T° — Trias

Cold water from shallow karst outs by Ragas spring located in early Cretaceous, which is an **overflow** spring, flowing through a karst chimney-shaft. In downstream, the water is warmer and more mineralized due to **deep circulation** and **trias signature** (high SO_4^{2-}).
Here we show specific conductivity and temperature of Ragas and St Antoine springs. The difference between temperature and electric conductivity of these two springs is the same in low-water and high-water period.

Dardennes springs (here Ragas) and St Antoine show strongs variations of flows during the year, which are explain a **karst system** functioning.

$Q_{Dardennes\ MIN} = 0.2 m^3/s$
$Q_{Dardennes\ MAX} = 40 m^3/s$

$Q_{St\ Antoine\ MIN} = 0.02 m^3/s$
$Q_{St\ Antoine\ MAX} = 4 m^3/s$



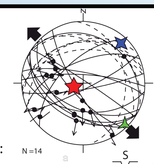
RESULTS 2

- LOCAL SCALE : FZ2

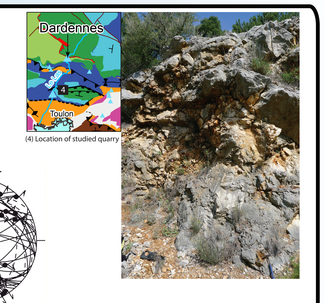
Quarry of the Mont Faron : microtectonic

1/ During tectonic inversion (Late Cretaceous) : extensive deformation

2/ Pyrenean-Provence compression (Paleogene)

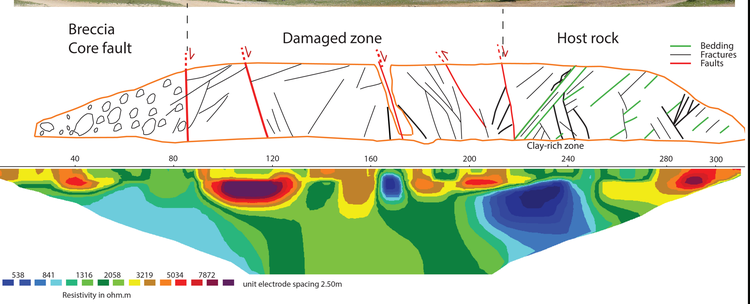


Reactivation of normal faults in thrust or slip faults : breccia



(4) Location of studied quarry

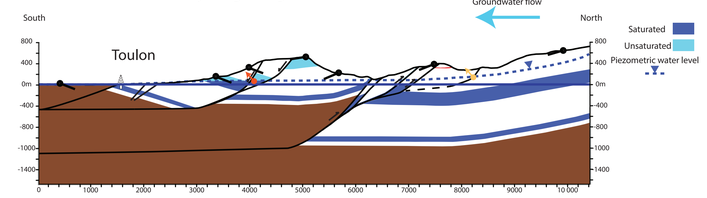
North South



The quarry is composed of **early cretaceous** rock with 3 different zones. At the South, we observe the **host rock** with first, Berriasian limestones and marls which have low resistivity (≈400 ohm.m). Futher to the North, a fractured zone without visible bedding is very heterogeneous in resistivity values. Highly resistivity values (≈7800 ohm.m) are due to unfractured limestone or limestone blocks. At the center of this **damaged zone**, there is a clay-filled fault with very low resistivity (450 ohm.m). Finally, the fault core is a polygenic **breccia** or cataclasites rock with mean resistivity of 800 to 1000 ohm.m. This zone is composed of limestone blocks with various aspects in size, more or less cemented and karstified. This zone is able to store water ressources.

CONCLUSION

Hydrogeological cross-section



- Normal faults reactivation produces high deformation : fault **zone** creation (breccia).
- Karst network in link with highly fractured zones.
- **Multiple compartments** for groundwater ressources : storage zone in depth (Trias to early Cretaceous), different fault zones explain transfer or storage zones.
- **Superposed aquifers** with different hydrochemical signatures.

Perspectives

Precise **chronology** of different phases of **reactivation and karstification** during compression with isotopic geochemical data ($d^{18}O$, $d^{13}C$) and compare to **water stable isotopes**. If current water flows through karst fractures, it must be influenced by isotopic values of cement fractures, and if water is mainly stored into the host rock, it shoul be mainly influenced by initial value of host rock.

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PhD - Karsteau